VEGETATION AND SOIL FACTORS IN RELATION TO SLOPE POSITION ON FOOTHILL KNOLLS IN THE UINTA BASIN OF UTAH

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Abstract.— Vegetation and soil differences with respect to slope position were studied on foothill knolls in the Uinta Basin of Utah. Plant communities on windswept ridges (top of slope) exhibited several unique characteristics when compared to the other slope communities. These communities at the top and base of slopes were sufficiently different in respect to plant life form composition, plant cover, wind-adapted growth forms, and percent exposed rock that they should be considered separate community types. Mineral concentrations in plant tissue and soil samples declined downslope in some cases and increased in others. Diversity decreased downslope as shrubs became dominant over grasses and forbs. Management of these communities should require special consideration due to the changes in the community structure with slope position.

Vegetation composition, soil factors, and their changes in response to exposure and slope position have received increased attention in recent years (Harner and Harper 1973, Jaynes and Harper 1978, Bloss and Brotherson 1979). The foothill knolls in the Uinta Mountains of Utah are little known ecologically and thus offer opportunities to further our knowledge of such relationships. These foothill knolls, many of which lie adjacent to mountain stream drainages, receive incessant winds, thus creating a unique plant community. Ecological studies of windswept plant communities have generally been restricted to high alpine ridges (Marinos 1978). Little research has been done on such communities at lower elevations (i.e., 2000 and 3000 m).

Anderson et al. (1976) described windswept ridges in south central Wyoming as a vegetative type. The areas so described were ridges that received strong southwesterly winds and had a cover of mat-forming plants. Establishment of the sagebrush-grass community of less windy spots in the area was apparently precluded by the winds. The dominant plant species was Lyal's goldenweed (*Haplopappus lyallii*). Plant cover for the community was estimated to be about 33 percent. Soils in the area were moderately textured (sandy loam to sandy clay loam), with soil depth averaging 17 cm. Exposed rock was twice as great at the top of the slope as at the bottom.

Mineral concentrations in vegetation and soil with respect to slope have not been studied to any extent. Harner and Harper (1973) looked at the increase in mineral concentration in vegetation along a moisture gradient. They concluded that increasing soil moisture permits greater solubility and, therefore, greater absorption of minerals in more productive sites. Fairchild and Brotherson (1980) used topographic position and slope aspect data as independent variables in statistical analyses of shrub habitats in conjunction with mineral concentration in the shrubs and soil.

The objective of this study was to determine the ecological relationships (vegetative and soil) of plant communities, some of which are windswept, with respect to slope position. Knowledge of vegetation and soil differences with respect to slope position should be useful for range managers planning treatment programs (i.e., brush control, range reseeding, etc.). Such would be especially true in areas similar to those described in this study, because much of Utah's big game winter ranges occur in similar topographic locations.

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Study Area

The Uinta Basin is characterized as a broad, elongated, asymmetric basin lying in the northeastern corner of Utah and extending into northwestern Colorado (Brotherson 1979). The central portion of the Uinta Basin is considered a cold desert giving rise to extensive pinyon-juniper forests with a bookcliff type topography (Greenwood and Brotherson 1978). The foothill areas of the Uinta Mountains that lie above the pinyon-juniper forests are dominated by mountain brush. The study area (north and west of Mountain Home, Utah) was located in the mountain brush vegetational zone on three foothill knolls at the foot of the Uinta Mountains. The elevation of the area ranges between 2400 and 2800 m. Climate is highly variable, with cold winters and hot dry summers. Annual precipitation in the area is between 30 and 35 cm, coming mostly in the form of snow during the winter. The area is used as late winter and early spring range for sheep and winter range for elk, deer, and sage grouse.

The communities studied were similar in that all areas display northeast-southwest exposure. Winds generally blow out of the west and are channeled down mountain stream drainages to the west of the study areas.

The windswept side of the communities, especially near the crest of the hill, is dominated by low mat-forming plants, some with the life form of a forb above ground and a shrub below ground. The leeward side is dominated by plants similar to those found on the windward side near the top. The vegetation downslope, where soils are deeper and receive increased moisture from snowdrifts, is dominated by tall shrubs.

Methods

Three hills were studied within a 26 km^2 area. All had similar exposure, slope, and elevation to insure that meaningful comparisons could be made. Each hill was sampled on both northeast and southwest sides at the top, middle, and bottom slope positions. A total of 90 plots (3 × 3 m) were sampled (30 plots per hill and 15 plots per side). Five plots each were placed along the contour at the top, middle, and bottom of each hill.

Study areas were marked with nylon cord 12 m long with a loop tied every 3 m. The four corners were secured with wooden stakes. Flagging of alternate colors was tied at equal intervals to help insure uniform placement of the 0.25 m^2 quadrats used to subsample each area. Four subsamples were taken within each 3 × 3 m area. Density of shrubs was determined from direct counts of all shrubs within the 0.25 m^2 quadrats. Percent cover was taken in each 0.25 m^2 quadrat for each plant species, rock, bare ground, and litter. Cover values were estimated as suggested by Daubenmire (1959), with some modification. The cover classes: (1)0.01–1.0 percent, (2)1.1–5.0 percent, (3)5.1–25 percent, (4)25.1–50 percent, (5)50.1–75 percent, (6)75.1–95 percent, and (7)95.1–100 percent were weighted to the lower end, in an attempt to make the system more sensitive to large numbers of low-growing species of plants and not to overestimate those plants near the top of the ridges where percentage of exposed rock is greatest. Height of species was also measured. Where a species was represented by less than 5 individuals per plot, all individuals were measured. For species represented by more than 5 individuals per 0.25 m^2 quadrat, 5 individuals were selected at random for measurement.

Soil penetration was measured with a 1-m penetrometer. Depth measures were taken 5 times in each 0.25 m^2 plot. Measurements were taken once at each corner and once in the middle. A total of 20 soil depth measurements was taken within each 3 × 3 m plot.

Soil samples were taken from each corner and middle of each 3 × 3 m plot. These 5 samples were then combined to get a representative sample of the whole plot. Soil samples were analyzed for texture, pH, soluble salts, and mineral ion concentrations (i.e., calcium, magnesium, potassium, sodium, iron, manganese, zinc, copper, nitrogen and phosphorus). Texture was determined as suggested by Bouyoucos (1951). Soil reaction was determined with a glass electrode pH meter. Soluble salts and pH were determined on saturated soil pastes having a 1:1 soil to water ratio (Russell 1948). Organic matter was determined by heating soil samples for 24 hours at 450 C. Differences in weight before and after heating were converted to percent organic matter.

Three soil samples from each slope position were randomly chosen out of the five taken for analysis of mineral concentrations. Individual ion concentration was determined by a Perkin-Elmer Model 403 atomic absorption spectrophotometer (Isaac and Kerber 1971). Potassium, magnesium, calcium, and sodium ions were extracted with a 1 percent neutral normal ammonium acetate solution (Jackson 1958, Hess 1971, Jones 1973). Zinc, manganese, iron, and copper were extracted by using DTPA-diethylenetriaminepenta-acetic-acid extracting agent (Lindsay and Norvell 1969). Soil phosphorus was extracted by sodium bicarbonate (Olsen et al. 1954). Total nitrogen analysis was made using a macro-kjeldahl procedure (Jackson 1958).

Plant samples for chemical analysis were taken randomly at each slope position from within the 3 × 3 m plots. Current year growth for shrubs and all aboveground tissue for forbs and grasses was clipped. The samples were air dried and ashed at 450 C for 24 hours. The ash analysis was made with the atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

The environmental factors measured in this study to characterize the communities on foothill knolls near the Uinta Mountains exhibited several general patterns (Table 1). Soil depth was found to be greatest in the midslope position of both the windward and leeward sides (18.5 and 27.7 cm respectively) of the hills. This is possibly the result of sufficient moisture to move the soil from the tops of the ridges but not enough to force the soil outward from the slope base. The leeward position is unique with respect to the other positions as the area receives most of its moisture from the increased accumulation of snow from drifts due to snow accumulation on the leeward side. The areas also have a northeasterly exposure; thus their snow cover remains longer. The result is increased moisture being available to plants for longer periods during critical early growth stages. The leeward position was dominated by Big Sagebrush (*Artemisia tridentata*) and Utah Serviceberry (*Amelanchier utahensis*).

The highest percent exposed rock (61.9 percent) was found on the windward side at the top-slope position; rock then steadily decreased downslope (Table 1). Top positions receive the greatest impact from winds, which sweep away snow and much soil and leave exposed rock. The leeward position shows much less exposed rock (25 percent) but displays a similar trend downslope. Midslope positions probably receive part of the soil blowing in from the windward side. Exposed bare ground and litter cover generally increased downslope. Organic matter and total soluble salts increased slightly downslope (Table 1), and pH showed slight decreases.

Plant life form data (Table 2) give an indication of patterns produced by variation in the relative cover of each life form class. Shrubs increased in relative cover downslope on both sides of the knolls. In contrast, shrub density decreased slightly downslope. This was due to larger plants at the bottom (Table 2) giving a lower density of shrubs but a greater percentage of cover. The midslope position had more species of small shrubs than did the bottom. The shrubs in the top position were small and mat forming, thus giving the lowest cover value for the shrubs (6.0 percent).

TABLE 1. General environmental factors downslope on windswept communities.

Environmental factor	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Soil penetration	6.7	18.5	16.4	6.7	27.7	21.6
Bare ground (%)	20.1	40.0	41.0	20.8	14.9	21.1
Rock (%)	61.9	38.3	13.2	25.2	4.0	14.7
Litter (%)	27.3	30.5	46.0	41.8	67.7	59.4
Organic matter (%)	6.6	8.1	8.3	7.4	6.6	6.9
pH	7.1	7.0	6.9	6.9	6.9	6.7
Soluble salts (ppm)	181	432	357	207	162	275

Forbs showed their highest cover (13.6 percent) at the top of the windward side of the slope (Table 2) and then decreased downhill. The windward side decrease was much greater than the leeward side. Forbs were poorly represented on the leeward side. The increased density and percent shrub cover on the leeward side probably crowd out forbs.

Grasses showed a relatively constant percent cover on both sides (Table 2). The windward side had a slight decrease in percent cover, but the leeward side had a slight increase. Both had lower percent cover values at the midslope position than at the other two. At the top of the windward side, grasses had a greater percent cover (14.8 percent) than any of the other life form types.

Percent cover for plant species thought to be successful on the windswept ridges (i.e., showed growth forms adapted to windy conditions) were considered together in a group called wind-adapted plants. Plants in this group were mat forming, rhizomatous, or formed rosettes. Cover for species in this group (15.6 percent) was greatest at the top of the windward side (Table 2). The top position of the leeward side had the second largest cover value (8.3 percent). The lowest cover value (1.1 percent) for this group was at the midslope position of the leeward side, which was dominated by tall shrubs. Height of plants was greatest, soil penetration was greatest, and moisture is assumed to be maximal because the largest snowdrifts accumulated there.

The Uinta Basin experienced a drought throughout the first half of 1977, the spring being extremely dry following record low moisture accumulations during the winter. This may explain the low percentage of annuals in the study area. The annuals either did not germinate that year or appeared before the study was initiated.

The average height of all vegetation at each slope position closely paralleled soil depth on the same slope. Vegetation height and soil depth were significantly (positive) correlated ($P < 0.01$), both tending to increase downslope on both windward and leeward sides (Table 2). The leeward side, however, showed an increase in height at the middle position (24.6 cm), then a decrease again at the bottom (19.2 cm). The increase in height can be accounted for by the presence of populations of Utah serviceberry at this midslope position.

A diversity index (Levins 1966, MacArthur 1972) was determined by using percent cover of each plant at each position (Table 2). Diversity decreased on both sides of the knoll downslope. The top position on the leeward side had the highest diversity (9.4). The lowest diversity (3.5) was at the bottom of the leeward side. A Shannon-Weiner (1949) diversity index was also computed and showed similar trends to that of the $1/\text{Sum } Pi^2$ diversity index.

Cluster analysis (Sneath and Sokol 1973) was used to group slope positions on the basis of vegetative cover (Fig. 1). The bottom-slope positions of both sides of the knolls were the most similar with respect to each other. The top-slope position on the windward side of the knolls was the most different vegetatively of any of the slope positions with respect to all others. This and other evidence indicates that the top of the slope on the windward side is unique with respect to

TABLE 2. General biotic factors downslope on windswept communities.

Biotic factor	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Life form (% cover)						
Shrub	6.0	21.0	21.4	19.3	26.7	30.0
Forb	13.6	2.0	4.4	4.8	4.4	2.9
Grass	14.8	9.2	12.0	14.6	13.5	15.1
Annual	0.2	0	0.1	0	0.2	0.3
Wind-adapted plants	15.6	3.6	3.7	8.3	1.1	2.6
Shrub density	8.7	7.3	6.0	11.9	12.1	8.9
$\bar{X}$ height (cm)	9.4	16.7	17.1	12.0	24.6	19.2
Diversity ($1/\text{Sum } P^2$)	6.9	4.4	3.9	9.4	6.4	3.5
$\bar{X}$ No. of plant species	14.7	10.3	13.0	17.0	17.7	16.7

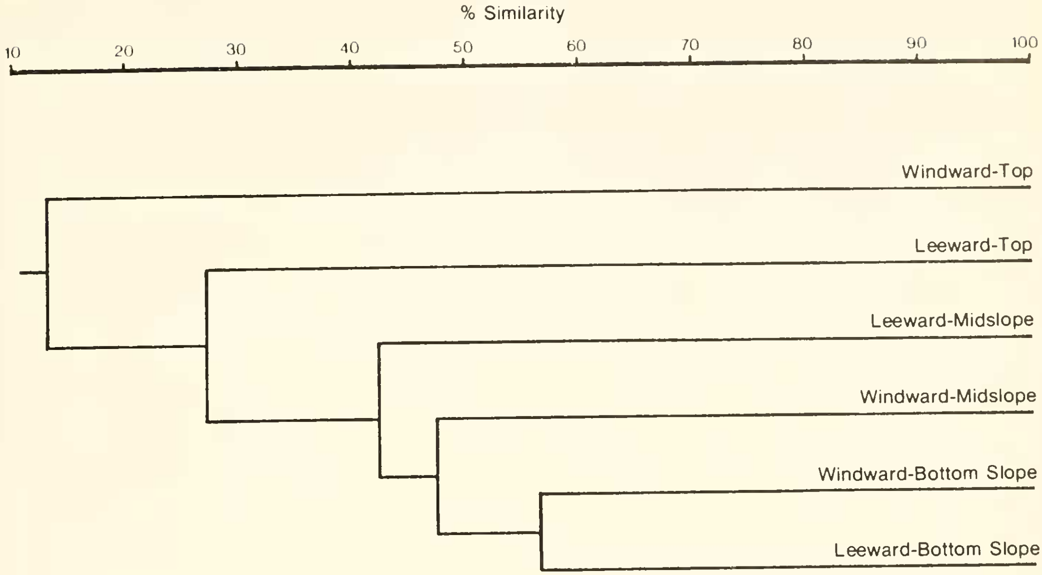

Fig. 1. Phenogram of the relationships between the slope position communities. Cluster is based on species cover values.

the remainder of the hill. There exists an area that could well be classified as a separate vegetation type with regard to the surrounding plant community. Anderson et al. (1976) stated that windswept communities are restricted to the ridges where the more competitive sagebrush can't tolerate the desiccating winds and rockier soil. The areas provided habitat for low, mat-forming plants. The area had an average plant cover of 33 percent and compares closely to this study, which has an average plant cover in the same position of 34.6 percent.

The average number of plants per slope position used to develop a prevalent species list is shown in Table 3. The windward side

Table 3. Prevalent species (% cover) for foothill knolls in the Uinta Basin, Utah.

Species	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Artemisia tridentata	0.0	13.6	18.3	11.5	11.8	23.8
Xanthocephalum sarothrae	0.4	0.4	0.0	2.2	0.0	0.9
Amelanchier utahensis	0.0	0.4	0.4	2.1	5.9	0.0
Phlox bryoides	10.3	1.7	3.4	0.4	0.6	1.1
Koeleria cristata	1.4	0.4	2.2	0.1	1.6	1.1
Stipa comata	4.6	0.0	1.0	2.6	0.8	0.6
Antennaria parvifolia	0.0	0.0	0.2	0.3	0.0	0.4
Bouteloua gracilis	1.6	1.1	0.0	4.1	0.0	0.0
Poa fendleriana	0.0	1.0	1.1	4.0	0.0	0.8
Artemisia cana	0.8	0.2	0.1	0.8	0.0	0.0
Artemisia frigida	4.6	1.1	0.0	0.6	0.0	0.0
Agropyron spicatum	4.4	4.8	6.1	1.7	8.1	8.8
Eriogonum heracleoides	0.0	0.0	0.1	1.0	1.1	0.0
Berberis repens	0.0	0.0	0.0	0.9	0.4	0.0
Penstemon sp.	0.0	0.0	0.0	0.6	1.6	0.2
Symphoricarpos oreophilus	0.0	0.0	1.7	0.6	8.0	2.6
Elymus ambiguus	1.8	1.8	1.5	0.0	0.0	4.2
Purshia tridentata	0.0	0.0	0.0	0.0	0.0	2.3
Cercocarpus montanus	0.0	4.9	0.0	0.0	0.0	0.0
Chrysothamnus greenei	0.0	0.0	0.4	0.0	0.0	0.0

had an average of 12.7, but the leeward side was much higher with 17.1 species.

A prevalent species list was developed for each slope position based on the average number of species per position and percentage cover (Table 3). Plant cover was generally low at most positions. Forbs and grasses exhibited reduced growth due to soil droughtiness, thus contributing less to the overall percent cover. Total percent cover increased downslope. The lowest percent plant cover (37.0 percent) on the leeward side was higher than the highest percent cover value (36.7 percent) on the windward side. The largest percent plant cover (46.4 percent) was at the bottom position of the leeward side of the knoll but had the highest concentration of a single species to the total. Big sagebrush (*Artemisia tridentata*) provided 23.8 percent cover (51 percent of the total plant cover for the bottom position). The highest percent cover on the windward side was again at the bottom position (36.7 percent), where big sagebrush (18.3 percent absolute cover) contributed 50 percent of the total cover (Table 3).

Two species were found in study plots at all slope positions: Moss phlox (*Phlox bryoides*) and Bluebunch wheatgrass (*Agropyron spicatum*). Big sagebrush exhibited the highest percent cover of any species at all except on the top slope position on the windward side, where it did not occur. The sites on the windward side were dominated by Moss phlox (10.3 percent); Needle and Thread (*Stipa comata*), (4.6 percent cover); Fringed sagebrush (*Artemisia frigida*), (4.6 percent); and Bluebunch wheatgrass (4.4 percent).

Soil ion concentrations ranged from a low of 0.6 ppm for copper at the midslope position on the leeward side to a high of 5947 ppm for calcium at the midslope position on the windward side (Table 4). Concentrations of minerals between windward and leeward sides generally followed similar patterns. Zinc is the only ion to decrease downslope on one side and increase downslope on the other. Calcium and iron generally decreased downslope, but phosphorus, manganese, nitrogen, magnesium, and potassium showed increases (Table 4). Nitrogen, calcium, magnesium, and potassium occurred in high concentration on both exposures. Epstein (1972) suggested that for soils to maintain healthy plant tissue, a soil concentration of 200 ppm of phosphorus is required. Both exposures had 10 percent or less of this concentration of phosphorus in the soil.

Mineral concentrations in plant tissue remained level or generally increased downslope on the windward and leeward exposures. Ion concentration in the plants ranged from 8 ppm for copper on the top position of the leeward side to 23,000 ppm for nitrogen at the midslope position of the leeward side (Table 5). The high concentration of nitrogen in the midslope position on the leeward side corresponds with the highest percent litter (67.7 percent). This can be attributed to an increase in nitrogen fixation by free-living microorganisms in and under litter mats (Charley 1977).

The mean ion concentration for copper in plant tissue was considerably lower (10 ppm) than the mean of 28.9 ppm found by Brothersen and Osayande (1980) in True Mountain Mahogany (*Cercocarpus montanus*) 30 km to

TABLE 4. Soil mineral concentration downslope on windswept communities.

Minerals (ppm)	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Zinc	1.3	1.4	1.5	2.1	1.6	1.2
Iron	16.4	10.9	14.5	21.2	21.1	17.0
Phosphorus	11.9	10.8	15.8	13.9	13.8	20.1
Manganese	12.0	11.3	18.0	12.7	15.0	18.7
Copper	0.8	0.9	1.2	0.7	0.6	0.9
Sodium	42.0	42.3	41.0	40.3	35.7	41.0
Nitrogen	2000.	1400.	1800.	2100.	2000.	1900.
Calcium	3971.	5947.	3790.	3378.	2853.	2558.
Magnesium	168.	606.	491.	223.	230.	338.
Potassium	169.	232.	300.	208.	200.	288.

the southeast in the pinyon-juniper woodland. The concentration is well below the 20 ppm suggested by Baker (1974) as being toxic to some ruminant animals. The highest concentrations of copper (11 ppm) were found at the bottom positions of both exposures.

Concentrations of the macronutrients (iron, phosphorus, nitrogen, calcium, magnesium, and potassium) in the plants were high and the concentrations of micronutrients were low. Ion concentrations in the plants were found to be adequate for higher plants to maintain a healthy condition (Epstein 1972). Minerals concentrated in plant tissue varies in meeting the nutritional requirements of sheep and cattle that graze the area. Most minerals met or exceeded the mineral requirements of sheep and cattle (NRC 1976). Copper (8–11 ppm) and iron (308–706 ppm) were the only two elements present in quantities considered to be toxic. Copper within the 8–25 ppm range is considered to be toxic to sheep. Iron exceeded the toxic level for cattle (400 ppm) in three of the six slope positions. Because the mineral concentration in plant tissue was determined from a combination of all the plants within each area, some plant species high in these minerals may be unpalatable to animals and not part of their diet.

The ratio of mi neral concentration in the plant versus the soil shows to what extent the plants take up and concentrate the minerals (Table 6). The highest ratio was found for phosphorus, which was 108 to 176 times more concentrated in plant tissue than in the soil. The lowest ratio for mineral concentration was for manganese (2.1) at the bottom-slope position of the leeward side. Manganese had the lowest concentration ratio for all the minerals at all of the positions (Table 6).

Potassium had the second highest ratio, ranging from a low of 48.3 at the bottom-slope position to a high of 81.0 at the top, both on the windward side. Potassium, the only monovalent cation essential for all higher plants, is inefficient as a cofactor in enzyme systems and plants have evolved the ability to take up large concentrations from the soil (Epstein 1972).

The mineral concentrations in the soil and plants, plant life form, and other environmental factors were subjected to correlation analysis (Table 7). Several significant correlations developed within and among the groups in relation to changes downslope. Soil depth was positively correlated with plant height; thus, as soil became deeper downslope, plant height increased. Soil depth was negatively correlated with plant density; thus, as shown earlier, shrub density was highest at the top of the hills where soil was shallowest (Table 7A).

Shrubs as a life form were negatively correlated with forbs. Consequently, as shrubs increased downslope forbs decreased (Table 7A). Cover for forbs (13.6 percent) was highest at the top position on the windward side, where shrub cover (6.0 percent) was lowest. Shrubs were also highly correlated with plant height. Forbs were negatively correlated with height downslope. Percent cover by forbs (13.6 percent) was highest at the top position on the windward side, where plant height was lowest (9.4 cm). Grasses were not correlated either positively or negatively with either shrubs or forbs. Percent cover by grasses was not associated with plant height

TABLE 5. Plant mineral concentrations downslope on windswept communities.

Minerals (ppm)	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Zinc	14.0	23.7	25.0	15.7	20.7	23.7
Iron	308.	491.	627.	379.	366.	706.
Phosphorus	1,400.	1,900.	2,200.	1,500.	1,900.	2,400.
Manganese	35.	38.	70.	45.	67.	40.
Copper	10.	9.	11.	8.	9.	11.
Sodium	226.	250.	287.	237.	249.	287.
Nitrogen	20,000.	21,000.	21,000.	20,000.	23,000.	21,000.
Calcium	7,800.	9,400.	15,400.	9,300.	10,000.	8,700.
Magnesium	1,800.	2,400.	2,800.	2,100.	2,300.	2,000.
Potassium	13,700.	13,600.	14,500.	13,300.	13,400.	14,200.

as were shrubs and forbs. Forbs as a life form were not positively correlated with any factor and grasses were not negatively correlated with any factor. Plant height was negatively correlated with density because the highest density was at the top of the ridges where height was lowest.

Soil minerals tended to be more positively than negatively associated with the other factors (Table 7B). Grasses were positively correlated with phosphorus and nitrogen downslope. Two studies have shown that an increase in phosphorus and nitrogen increases the amount of biomass produced on rangelands (Barrett 1979, Wight 1976). Magnesium was the only soil mineral positively correlated with shrubs. Copper was highly correlated with several factors in the soil and plants (Table 7B). It was the only mineral to be correlated either positively or negatively between the plant and soil.

As above, mineral concentrations in plants were also more positively than negatively correlated with the other factors. Zinc, iron, and phosphorus were positively associated with shrub cover. These minerals increased downslope as did percent cover by shrubs. Forbs showed the reverse trend, with percent cover by forbs decreasing downslope as zinc, iron, and phosphorus increased. Nitrogen in plants was positively correlated with plant height.

Vegetative and soil differences in areas subjected to high winds develop characteristics that distinguish them from the surrounding plant community. The tops of the windswept ridges have several unique features (i.e., percent exposed rock, soil depth, plant height, plant cover, and composition of life form). Management of these areas for livestock or wildlife should include special considerations. The windswept ridges during winter are often snow-free while the surrounding areas are covered. This would tend to concentrate animals in these areas and cause overgrazing. Also, these areas are the first to green up in the spring due to the exposure, which may be why animals graze these areas while plant carbohydrates are low.

Improvements or rehabilitation of these areas (i.e., brush control, range reseeding, etc.) by range managers must be looked at closely. Anderson et al. (1976) showed in Wyoming that windswept areas had a different relative cover by palatability class than the surrounding vegetation type, even though both areas rated fair for range condition. Plant types and species used to improve these areas must be able to withstand the harsh environment of the windswept ridges. Life forms of the plants should show adaptation (i.e., low, mat forming, rhizomatous, drought- and cold-hardy grasses or forbs) able to withstand the unique environments of the sites.

Revegetation attempts in these areas would best be achieved by planting mixtures of seeds rather than using single seed species in reseeding projects. Mixtures would allow greater variability in the plant resource in meeting the needs of an ever-changing and varied habitat. Jaynes and Harper (1978) stated that species of undesirable forage value may be the only plant species available to meet the criteria of areas with harsh environments (such as windswept ridges). Vegetative cover to prevent erosion may have priority over palatable forage in certain areas.

TABLE 6. Plant and soil ratios of mineral concentrations with regard to slope position.

Minerals	Slope position windward side			Slope position leeward side		
	Top	Middle	Bottom	Top	Middle	Bottom
Zinc	10.8	16.9	17.9	7.5	12.9	19.8
Iron	18.8	45.1	43.2	17.9	17.3	41.5
Phosphorus	117.6	175.9	139.2	107.9	137.7	119.4
Manganese	2.9	3.4	3.9	3.5	4.5	2.1
Copper	12.5	10.0	9.2	11.4	15.0	12.2
Sodium	5.4	5.9	7.0	5.9	7.0	7.0
Nitrogen	10.0	15.0	11.7	9.5	11.5	11.1
Copper	2.0	1.6	4.1	2.8	3.5	3.4
Magnesium	10.7	4.0	5.7	9.4	10.0	5.9
Potassium	81.0	58.6	48.3	63.9	67.0	49.3

Management of windswept communities and ranges with rolling hill country, as discussed in this paper, should be preceded by a careful study of the vegetative and soil differences to insure successful management programs.

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TABLE 7. Correlation coefficients of environmental and biotic factors with respect to each other: Section A, life form, general vegetative and site factors; Section B, mineral concentration in the soil; Section C, mineral concentration in the plants; subscript "p," mineral concentrations in plant; subscript "s," mineral concentrations in soil; superscripts "2,3,4," significant levels as follows: 2 = 0.05, 3 = 0.02, 4 = 0.01.

Factor	Positive correlations	Negative correlations
A		
Shrub	Soil depth^2, height^4	Forb^4
Forb		Zn^2_p, shrub^4
Grass	Fe^4_s	
Annual		
Plant height	Soil depth^4, Zn^2_p, shrub^4	Plant density^3
Plant density	Fe^3_s,	Soil depth^4, height^3
Organic matter	Cu^2_s, Mg^4_s, Mg^4 soluble salts^4, Zn^4_p	
pH	Ca^4_s, Ca^2_p, Mg^2_p	Fe^4_s, P^2_s, Cu^3_s, Na^3_s, K^2_s, Fe^4_p, P^3_p, plant
Soluble salts	Cu^4_s, Ca^2_s, Mg^4_s organic matter^4, Zn^4_p,	
Soil depth	shrub^2, height^4	Plant density^4
B		
Zinc		
Iron	N^3_s	Ca^2_s, pH^4, Mg^2_p, Plant density^3
Phosphorus	Fe^2_s, Mn^4_s, Na^2_p,	Ca^2_s, K^3_s, pH^2
Manganese	P^4_s, K^4_s, Na^2_p	
Copper	Na^4_s, Mg^4_s, K^4_s, organic matter^2, soluble salts^3, Zn^4_p, Fe^4_p, Cu^2_p, p^3_p	pH^3
Sodium	Cu^4_s, Fe^3_p, P^2_p, Cu^2_p	pH^3
Nitrogen	Fe^3_S	
Calcium	pH^4, soluble salts^2, Mg^3_p	Fe^2_s, P^2_s
Magnesium	Cu^4_s, organic matter^4, soluble salts^4, Zn^4_p, Fe^2_p	
Potassium	P^3_s, Cu^4_s, Fe^4_p, Na^2_p	pH^2
C		
Zinc	Cu^4_s, Mg^4_s, organic matter^4, soluble salts^4, P^4_p, Cu^4_p, Height^2	Forb^2
Iron	Cu^4_s, Na^3_s, Mg^2_s, K^4_s, P^4_p, Cu^2_p	pH^4
Phosphorus	Cu^4_s, Na^2_s, Mg^2_s, Zn^4_p, Fe^4_p, Cu^4_p, K^2_p	pH^3
Copper	Cu^2_s, Na^2_s, Zn^4_p, Fe^2_p, P^4_p	pH^4
Sodium	P^2_s, Mn^2_s, K^2_s	
Calcium	Mn^4_s, Mg^4_s	Plant density^2
Magnesium	Ca^3_s, pH^3, Mn^3_p, Ca^4_p	Fe^2_s
Potassium	P^2_p	

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